DOE/PC/92521--T258

TECHNICAL REPORT
December 1, 1994 through February 28, 1995

Project Title: **MANUFACTURE OF AMMONIUM SULFATE FERTILIZER FROM FGD-GYPSUM**

DOE Cooperative Agreement Number: DE-FC22-92PC92521 (Year 3)
ICCI Project Number: 94-1/3.1B-3M
Principal Investigator: M.-I.M. Chou, Illinois State Geological Survey (ISGS)
Other Investigators: M. Rostam-Abadi, J.M. Lytle, and J.A. Bruinius (ISGS); R. Hoeft, University of Illinois, Urbana-Champaign (UIUC); S. Dewey, AlliedSignal-Chemicals; F. Achorn, Southeast Marketing Chem. Process Inc. (SE-ME)
Project Manager: D. D. Banerjee, ICCI

ABSTRACT

The overall goal of this project is to assess the technical and economic feasibility for producing fertilizer-grade ammonium sulfate from gypsum produced as part of limestone flue gas desulfurization (FGD) processes. This is a cooperative effort among the ISGS, the UIUC, AlliedSignal, SE-ME, Henry Fertilizer, Illinois Power Co. (IP), and Central Illinois Public Services (CIPS). Bench-scale experiments will be conducted to obtain process engineering data for the manufacture of ammonium sulfate from FGD-gypsum and to help evaluate technical and economic feasibility of the process. Controlled greenhouse experiments will be conducted at UIUC to evaluate the chemical impact of coal-derived impurities in ammonium sulfate produced from FGD-gypsum on soil properties. A process flow sheet will be proposed and market demand for the products will be established. An engineering team at IP will provide an independent review of the economics of the process. AlliedSignal will be involved in testing and quality evaluation of ammonium sulfate samples and is interested in an agreement to market the finished product. CIPS will provide technical assistance and samples of FGD-gypsum for the project.

In this quarter, with an exception of the neutron activation analysis, analyses of FGD-gypsum samples that were generated by two power stations were completed. The high quality FGD-gypsum sample produced from the Abbott power plant in Champaign, IL was 98.36% gypsum, $CaSO_4 \cdot 2H_2O$, and less than 0.01% calcium sulfite, $CaSO_3$. The low quality sample from CIPS's Newton Power Plant at Jasper, Illinois, was only 7.36% of gypsum. It was 87.54% calcium sulfite. A literature search provided the information to set up a batch, bench-scale reactor system. Reactions were conducted at 70°C for a range of times which resulted in 82% conversion of calcium sulfate to ammonium sulfate.

EXECUTIVE SUMMARY

Progress made under the United States Department of Energy's Clean Coal Technology program and the 1990 amendments to the Clean Air Act that mandate a 2-stage 10-million ton reduction in sulfur dioxide emissions in the United States have definitely promoted the use of FGD technologies. In addition to capital costs for equipment and operating expenses, plants burning high sulfur coal and using FGD technologies must also bear increasingly expensive landfill disposal costs for the solid waste produced. The FGD technologies would be much less of a financial burden if successful commercial uses were developed for the gypsum-rich by-products of the wet limestone scrubbing. Conversion of FGD-gypsum to a marketable product could be a deciding factor in the continued use of high-sulfur Illinois coals by electric utilities.

The conversion of FGD-gypsum to calcium carbonate and ammonium sulfate by reacting it with CO_2 and ammonia or by reacting it with ammonium carbonate is being studied in this program. A variation of this process could provide electric utilities a means to convert the CO_2 and SO_2 in their flue gas to useful commercial products. The fertilizer industry would also be provided with a large source of ammonium sulfate to supply sulfur nutrient in NPK fertilizer blends. The need of from five to 10 million tons annually of new ammonium sulfate production for the fertilizer market is anticipated.

Goals and Objectives

The overall goal of this project is to assess the technical and economic feasibility for producing commercial-grade ammonium sulfate fertilizer from FGD-gypsum. The project focuses on developing process engineering data, costs for the production of the fertilizer, and market demand for the product in the agricultural community. If successful, the results of this project could provide a solution, from both environmental and economic standpoints, to the problem of disposing of large quantities of by-products from FGD processes.

Specific objectives of this study are

I. Assess current knowledge on the chemistry, process schemes, and production costs of ammonium sulfate from gypsum.

II. Obtain samples of FGD-gypsum from two Illinois power plants for the work proposed in the project.

III. Obtain engineering data required for process scale-up and the technical and economic feasibility studies.

IV. Determine the influence of coal-derived impurities in the gypsum upon process conditions and the quality of the ammonium sulfate produced.

V. Evaluate the impact of continued use of FGD-gypsum-derived ammonium sulfate on soil chemical properties.

VI. Establish a process flow sheet for the production of ammonium sulfate from FGD gypsum and evaluate the production costs and the market potential for the product.

This project is a cooperative effort among the ISGS, UIUC, AlliedSignal, SE-ME, Henry Fertilizer, Illinois Power Co. (IP), and Central Illinois Public Services (CIPS).

The ISGS with consultation from SE-ME will conduct a literature search that will give insight into the chemistry, process schemes, and costs of producing ammonium sulfate from gypsum. ISGS will also conduct bench-scale experiments to obtain process engineering data for the manufacture of ammonium sulfate from FGD-gypsum and to help evaluate the technical and economical feasibility of the process. UIUC will conduct controlled greenhouse experiments to evaluate the chemical impact of the FGD-gypsum-derived ammonium sulfate on soil properties. A process flow sheet will be proposed and market demand for the products will be established. IP will provide an independent review of the economics of the process. AlliedSignal, a major producer and marketer of fertilizer grade ammonium sulfate, will carry out testing and quality evaluation of ammonium sulfate samples that are representative of a proposed product. This company will consider an agreement to market the finished product. CIPS will provide technical assistance and samples of FGD-gypsum for the project.

In this quarter, with an exception of neutron activation analysis, analyses of FGD-gypsum samples that were generated by two power stations were completed. The high quality FGD-gypsum sample produced from the Abbott power plant in Champaign, Illinois, has 98.36% of gypsum, $CaSO_4 \cdot 2H_2O$, and less than 0.01% calcium sulfite, $CaSO_3$. The low quality sample from CIPS's Newton Power Plant, Jasper, Illinois, has only 7.36% gypsum. It has 87.54% calcium sulfite. For the low quality Newton FGD-gypsum sample that contains mostly calcium sulfite, a conversion of calcium sulfite to calcium sulfate will be necessary. Various oxidative conversion processes are being tested in this quarter. These results will be reported in the next quarter.

A literature study on the chemistry and process schemes for ammonium sulfate production from gypsum was completed. The information was used to set up a batch, bench-scale reactor system for conducting preliminary tests. The quality of the ammonium sulfate samples produced from these tests was confirmed by both comparing their melting points with that of a commercial standard and by examining chemical analysis data. Based on the weight of the ammonium sulfate produced and its theoretical yield from a total conversion of calcium sulfate feed, a yield of up to 82% and a purity of up to 95.1% for the ammonium sulfate production was achieved. The results of the preliminary laboratory experiments suggest that high quality ammonium sulfate can be produced from the high quality Abbott FGD-gypsum sample at reaction temperature of 70°C and a duration of five to six hours. The current test condition will be modified in the next quarter in an attempt to improve both the quantity and quality of the ammonium sulfate produced.

Also, based on the literature information, capital costs estimates on producing ammonium sulfate from FGD-gypsum are being conducted, and the results will be reported in the next quarter.

GOALS AND OBJECTIVES

The overall goal of this project is to assess the technical and economic feasibility for producing commercial-grade ammonium sulfate fertilizer from FGD-gypsum. This project focuses on providing process engineering data, estimating costs for the fertilizer production, and evaluating marketability of the product in the agricultural community.

Specific objectives of this study are

I. Assess current knowledge on the chemistry, process schemes, and production costs of ammonium sulfate from gypsum.

II. Obtain samples of FGD-gypsum from two Illinois power plants for the work proposed in the project.

III. Obtain engineering data required for process scale-up and the technical and economic feasibility studies.

IV. Determine the influence of the properties of the gypsum and process conditions on the quality of the ammonium sulfate produced.

V. Evaluate the impact of continued use of ammonium sulfate on soil chemical properties.

VI. Establish a process flow sheet for the production of ammonium sulfate from FGD gypsum and evaluate the production costs and the market potential for the product.

INTRODUCTION AND BACKGROUND

Wet flue gas desulfurization (FGD) processes, that use limestone to scrub SO_2 from flue gas are advanced pollution control technologies that will remain preferred choices for Phase-II compliance because of their advanced level of commercial development and demonstrated operational experience. A FGD system installed on a 500-MW plant burning 3.5% sulfur coal, with a desulfurization efficiency of 95%, can generate about 47 tons of gypsum per hour if the conditions for oxidation of sulfite to sulfate are met. From an environmental and economic standpoint, it is desirable to use this by-product as a feed material to produce a salable product. The goal of this project is to assess the technical and economic feasibility for producing commercial-grade ammonium sulfate fertilizer from this gypsum.

Four major industries have agreed to work with ISGS on this project. AlliedSignal (Hopewell, VA), one of the largest producers of ammonium sulfate in the United States, is interested in developing a process to convert FGD-gypsum to granular ammonium sulfate. AlliedSignal will evaluate samples of the ammonium sulfate produced and consider making an agreement to market the finished product. Illinois Power (IP) and Central Illinois Public Services (CIPS), which have long advocated the development of markets for coal by-products, endorse the evaluation of the concepts proposed in this research project. IP will provide an independent review of the economics of the process and CIPS will provide technical assistance and samples of gypsum-sludge for testing. Henry Fertilizer (Henry, Illinois), will provide technical assistance on the project and will allow the use of their commercial facility if the project advances to a scale-up stage.

Regulations to reduce sulfur dioxide emissions in the year 1995 (phase I: 2.5 lbs $SO_2/10^6$ Btu) and the year of 2000 (phase II: 1.2 lbs $SO_2/10^6$ Btu) are mandated by the 1990 Clean Air Act Amendments. Millions of tons of high-quality gypsum may be produced in this decade. The total amount depends partly on additional installation of FGD systems. The amount of FGD-gypsum by-product could exceed the current demand of the FGD-gypsum industry. The anticipated problems for utilities are increased disposal costs plus limited landfill space. Successful commercial utilization of FGD by-products would improve the FGD economics.

The degree to which FGD-gypsum is commercially used depends on its quality. Currently, high-quality FGD-gypsum with purity greater than 94% is used mainly to manufacture construction materials, i.e. stucco and gypsum-plaster, gypsum wall boards, and cement. Lower quality FGD gypsum is less desirable and, unless a market materializes to use it, a significant percentage of this by-product will require disposal as a solid waste. Several methods for the use of low quality FGD-gypsum have been proposed and, in many cases, demonstrated. Stabilized FGD material can be used as a liner for a landfill. Some FGD materials are processed to a fixed stabilisate and disposed in abandoned surface coal mines. An alternate approach to utilize both high and low quality FGD-gypsum is to produce ammonium sulfate fertilizer.

Ammonium sulfate is a valuable nutrient source for both nitrogen and sulfur for growing plants. There is a growing demand for sulfur as a plant nutrient in the sulfate form because of diminished deposition of sulfur compounds from flue gas emissions and more sulfur is taken up by plants produced in high yields. Also, the trend of using high nitrogen content fertilizers has pressed incidental sulfur compounds out of traditional fertilizer. The current market for ammonium sulfate in the United States is about two million tons per year. It is anticipated that 5 to 10 million tons of new ammonium sulfate production may be required for fertilizer markets annually to make up for the loss of sulfur deposition from the increase ristriction on acid-rain. The fertilizer industry appears ready to accept an added source of fertilizer grade ammonium sulfate to supply sulfur in NPK fertilizer blends. Currently, the wholesale price for granular ammonium sulfate ranges from $75 to $130 per ton. At these price levels, converting some of the FGD-gypsum to ammonium sulfate becomes an attractive solution an Illinois disposal problem and could improve the economics of FGD systems in the state.

An ammonia-based FGD process, which produces ammonium sulfate as by-product, has been developed by General Electric (GE) and tested on a pilot-scale at the Great Plains Synfuel Plant in Beulah, ND. An economic study conducted by GE shows that for coals greater than 3% sulfur, this FGD process is favored over the forced oxidation process when the selling price of ammonium sulfate is greater than $40/ton. The annual levelized cost was shown to decrease with increasing sulfur content of the coal when the ammonium sulfate price is greater than $70/ton. There are no published reports on the economics of converting FGD-gypsum to ammonium sulfate.

EXPERIMENTAL PROCEDURES

Sample collection and preparation

Two FGD-gypsum samples were collected: one from the Abbott power plant in Champaign, Illinois, and one from the Newton Power Plant, Jasper, Illinois. The Abbott power plant operates a Chiyoda Thoroughbred 121 FGD-desulfurization system and produces 1 ton of gypsum (> 98% purity) for every 10 tons of coal burned. The Newton Plant operates a Unit 1 wet limestone scrubber system and produces mostly calcium sulfite(<10% gypsum). The FGD-gypsum samples were dried in ambient air for 2 to 4 days. A total of 58.5 pounds of sample from the Abbott plant was riffled into 32 bags. About 100 pounds of sample from the Newton plant was riffled into 64 bags.

Sample characterization

Physical and chemical analyses were conducted on both of the FGD-gypsums this quarter. Their particle size distributions were determined using manual and instrumental methods. The manual method passed the samples with water through a 100 mesh screen and then a 200 mesh screen. The weight % of the sample retained by each screen, as well as the weight % of sample that passed through both screens, was determined after drying. The MicroTrac II Analyzer determines particle size deviation by laser light scattering and reports the mean particle diameter and standard deviation. Its limits are 0.7 micron to 700 micron. Particles outside of this range are not detected by the machine.

The amounts of free water (released at 45°C) and the combined water (released at 230°C for gypsum), calcium oxide (CaO), magnesium oxide (MgO), and carbon dioxide in the two samples were determined by the ASTM C471 method. Based on these analytical results, the compositions were calculated in terms of $\%CaCO_3$, $\%MgCO_3$, $\%CaSO_4$, $\%CaSO_4 \cdot 2H_2O$, and $\%(NH_4)_2SO_4$.

Thermogravimetric analysis (TGA) was conducted under an air flow of 50 ml/min with programmed heating from room temperature to 900°C at 10°C/min. The weight loss profile and its first derivative were used for preliminary estimates of purity and composition.

Production of ammonium sulfate from FGD-gypsum

The chemistry of the process and process conditions have been reviewed and the information was used to set up a bench batch reactor system and to conduct the preliminary tests. The bench scale batch reactor system consists of a 1000-ml, three-neck, round-bottomed flask fitted with a mechanical stirrer, a condenser, and a thermometer. An autotransformer and heating mantle were used to control the reaction temperature. The procedures for preliminary tests to produce ammonium sulfate from the high quality Abbott gypsum sample follow.

FGD-gypsum was added to an ammonium carbonate solution (carbonate in 500 ml of distilled water) in the 1000-ml reaction flask. The temperature of the stirred mixture was raised from room temperature to 70°C, and maintained at that temperature for a range of times. The solution which contained the ammonium sulfate was separated from the solid byproduct, calcium carbonate, by vacuum filtration. The filtrate plus the rinsing, a total of about 600 ml of the liquid, was concentrated to a volume of about 150 ml on a constant temperature water bath. The residual concentrate was kept at room temperature for crystallization of ammonium sulfate. The condensation and crystallization processes were repeated until no more crystal could be produced. The combined product was dried under ambient air before the total weight measurement.

RESULTS AND DISCUSSIONS

Characterization of two FGD-gypsum samples

Samples of a high quality (Abbott plant) and a low quality (Newton plant) FGD-Gypsum were collected in the last quarter. Splits of the samples were subjected to chemical and physical analyses this quarter.

The data on particle size distribution obtained by passing the gypsum samples through a series of screens and by Microtrac II particle sized analyzer are shown in Table 1. The Newton plant by-product had a smaller average particle size than the Abbott plant by-product.

Table 1. Results of particle size analysis

	Abbott Power Plant	Newton Power Plant
% > 100 mesh	0.97	1.30
% 100-200 mesh	15.40	7.90
% < 200 mesh	83.60	90.8
average diameter (microns)	73.88	66.83
standard deviation	35.63	43.95

The results of chemical analyses and the calculations following ASTM 471 procedures are shown in Table 2. The sample from the Abbott plant has more combined water (water of hydration) than free moisture; the opposite is true for the Newton plant sample. This is because the Abbott sample has more of gypsum (98.36% $CaSO_4 \cdot 2H_2O$) and less of calcium sulfite (<0.01% $CaSO_3$) than the Newton sample.

Table 2. Results of gypsum byproduct analysis by ASTM

	Composition in wt. %, moisture free	
Analyzed Values	Abbott Power Plant	Newton Power Plant
combined water	20.59	1.54
CaO	32.92	44.80
MgO	0.01	0.38
SO_4	54.90	4.10
SO_3	<0.01	58.36
CO_2	0.71	1.60
NH_3	<0.01	<0.01
Free Moisture	<0.01	5.70
Calculated Values		
$CaSO_4 \cdot 2H_2O$	98.36	7.36
$CaCO_3$	1.60	2.70
$CaSO_4$	<0.01	<0.01
$CaSO_3$	<0.01	87.54
$MgCO_3$	0.01	0.80
$(NH_4)_2SO_4$	<0.01	<0.01

Samples have been submitted to the Analytical Section of the ISGS for trace metals analyses. The turnaround time for this analysis by the neutron activation technique is about three months.

The results from thermogravimetric analysis (TGA) are shown in Figure 1. The TGA curve of the Abbott gypsum is unique. All weight loss occurred between 98.56° C and

206.73° C (peak at 158.65° C). This weight loss is related to removal of the water of hydration from gypsum. The curve also shows that calcium sulfate from gypsum does not decompose below 900° C. The TGA curve of the Newton gypsum (Figure 2) is more complex. It shows no recognizable weight loss for water. However, it shows a weight loss between 259.62° C and 399.04° C (peak at 382.24° C), a weight gain between 399.04° C and 557.69° C (peak at 483.20° C), and a slight weight loss between 557.69° C and 632.21° C. The process for weight loss occurring between 259.62° C and 399.04° C is not known. It is possible due to decomposition of some impurities in the Newton sample. The process responsible for the weight gain between 399.04° C and 557.69° C is most likely due to oxidation of calcium sulfite $CaSO_3$ to calcium sulfate $CaSO_4$ during the thermogravimetric analysis. A slight weight loss occurring between 399.04° C and 557.69° C is due to the evolution of CO_2 as calcium carbonate ($CaCO_3$) in the sample decomposes.

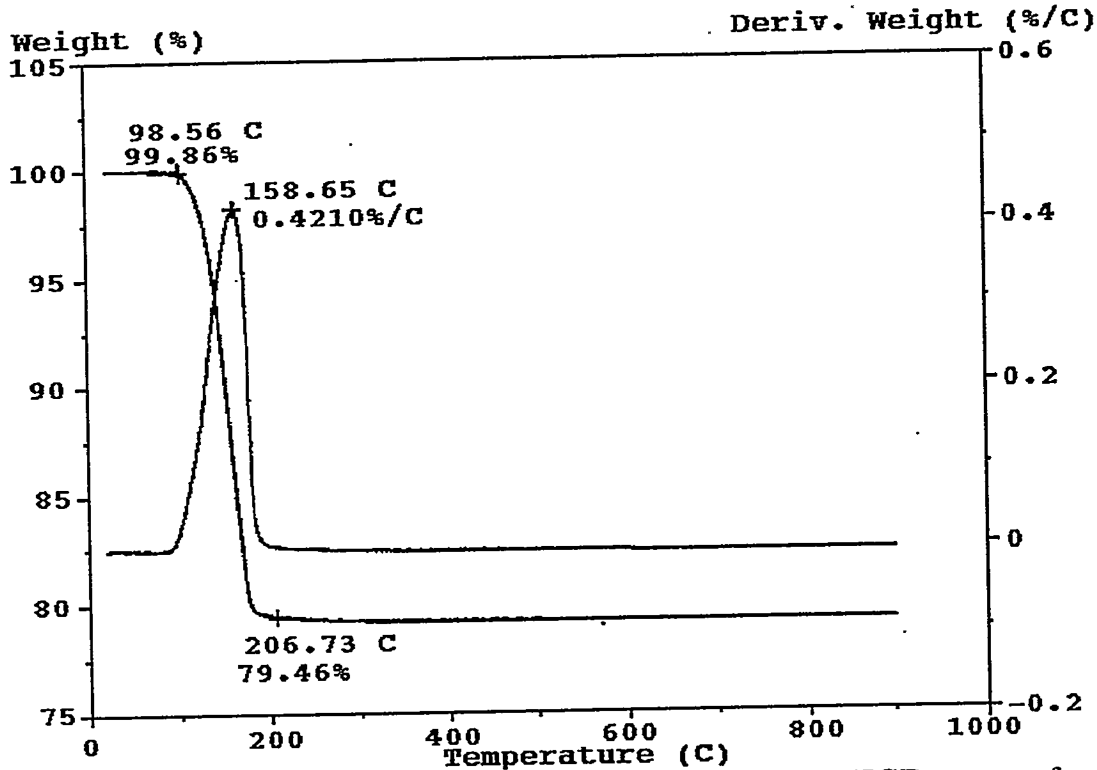

Figure 1: TGA weight loss profile and first derivative for FGD-gypsum from the Abbott Plant.

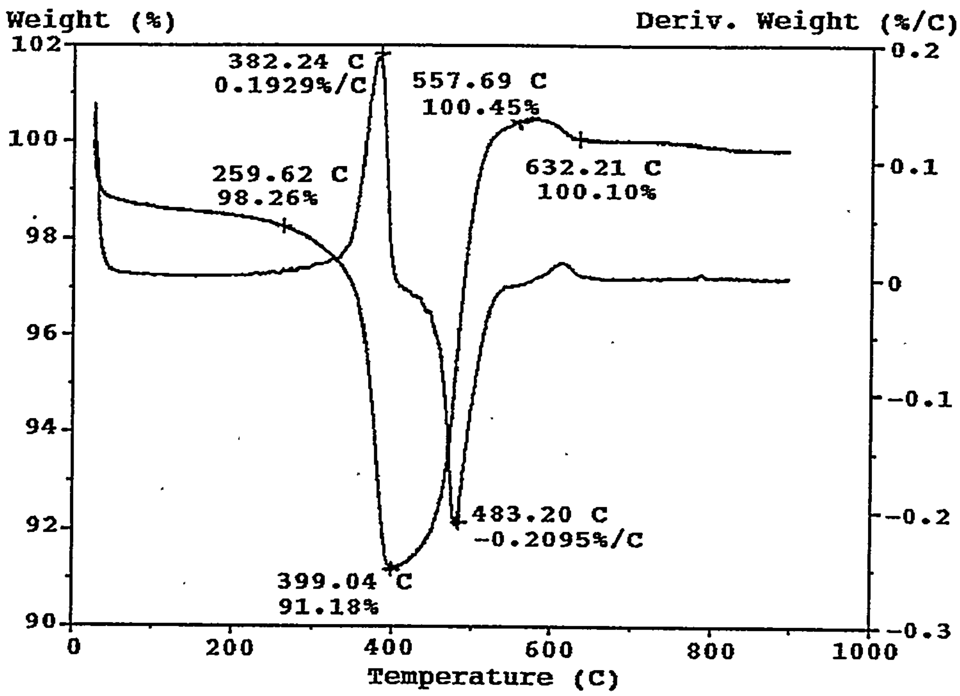

Figure 2: TGA weight loss profile and first derivative for FGD-gypsum from the Newton Plant.

Literature review

The process for producing ammonium sulfate by reacting gypsum and ammonium carbonate was first proposed in 1809 (Higson, 1951) and is commonly known as the Mersberg process. No literature cites plants using this process in the United States. However, plants in England (Higson, 1951) and India (Nitrogen, 1967) used this process at one time, but it is uncertain whether these plants are still in operation. The process was thought to be economically attractive in areas where sulfur is unavailable or very expensive (Kirk-Othmer, 1992). One reason for the cost of the process is that the reaction takes place in a series of reactors with a long residence time. The total residence time for the reaction to achieve 95% conversion is reported to be 5 hours at 70°C when the gypsum particle size is 95% passing 120 mesh (Higson, 1951 and Kenton, 1985).

In the early 1960's the TVA started working with the Mersberg process as a regeneration step subsequent to the production of ammonium phosphate fertilizers in bench scale (Blouin et al., 1970) and pilot scale (Meline et al., 1971). In the process, phosphate rock is extracted with nitric acid. The extract is reacted with ammonium sulfate to produce ammonium phosphate and gypsum as a by-product. The by-product gypsum was recovered and reacted with ammonium carbonate for the purpose of regenerating ammonium sulfate.

TVA developed a single stage reactor for regenerating ammonium sulfate for the process. The gypsum and ammonium carbonate are premixed before entering the reactor. The reactor (Figure 3) uses a recycle stream that flows upward in order to obtain larger $CaCO_3$ crystals which, in turn, facilitates filtration. Residence times of 0.5, 1, and 3 hours at 125°F (52°C) and 140°F (60°C) were tested. Conversions of greater than 95% were obtained (Blouin et al., 1970). Typical operating conditions for the process in the pilot plant were 120°F (49°C), 2 hours residence time, and ammonium carbonate feed at or above 105% stoichiometric requirement, and the conversion was 98% (Meline et al., 1971). The particle size of the gypsum had an effect on the particle size of the $CaCO_3$. P_2O_5 affected the $CaCO_3$ filtration rate adversely.

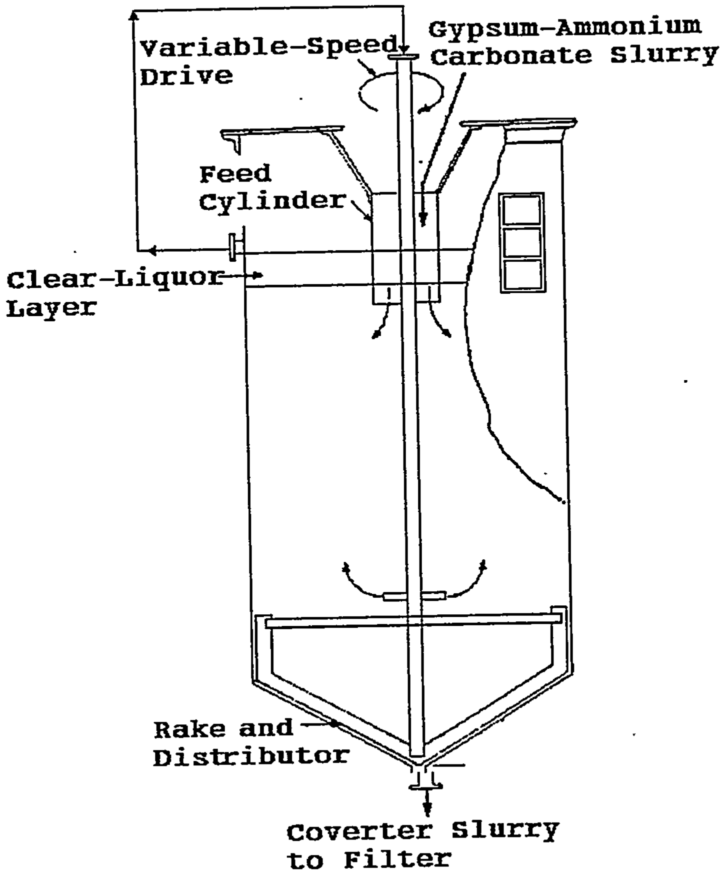

Figure 3: TVA's gypsum conversion reactor.

Preliminary bench scale testing for ammonium sulfate production

The critical reaction for producing ammonium sulfate from the FGD-gypsum is the reaction between ammonium carbonate and calcium sulfate. In the preliminary tests, the high quality gypsum from Abbott plant was used to react with reagent grade ammonium carbonate. The purity of the ammonium sulfate samples produced from these tests is first confirmed by comparing their melting points with that of a commercial standard (Table 3). Based on the weight of the ammonium sulfate produced a yield of 35% and 82% was achieved. Chemical analysis on the 82% yeild product showed that the purity of the ammonium sulfate was 95.1%.

Table 3. Melting points of ammonium sulfate

$(NH_4)_2SO_4$	Melting Point (°C)
Standard sample	240.0
Sample from run #1	242.0
Sample from run #2	238.2

The by-product solid residue produced from ammonium sulfate production was isolated and subjected to TGA analyses. The TGA curve of one of the residues is shown in Figure 4. The graph shows a weight loss occurring between 600°C and 770°C. This is attributed to the evolution of carbon dioxide from decomposing calcium carbonate.

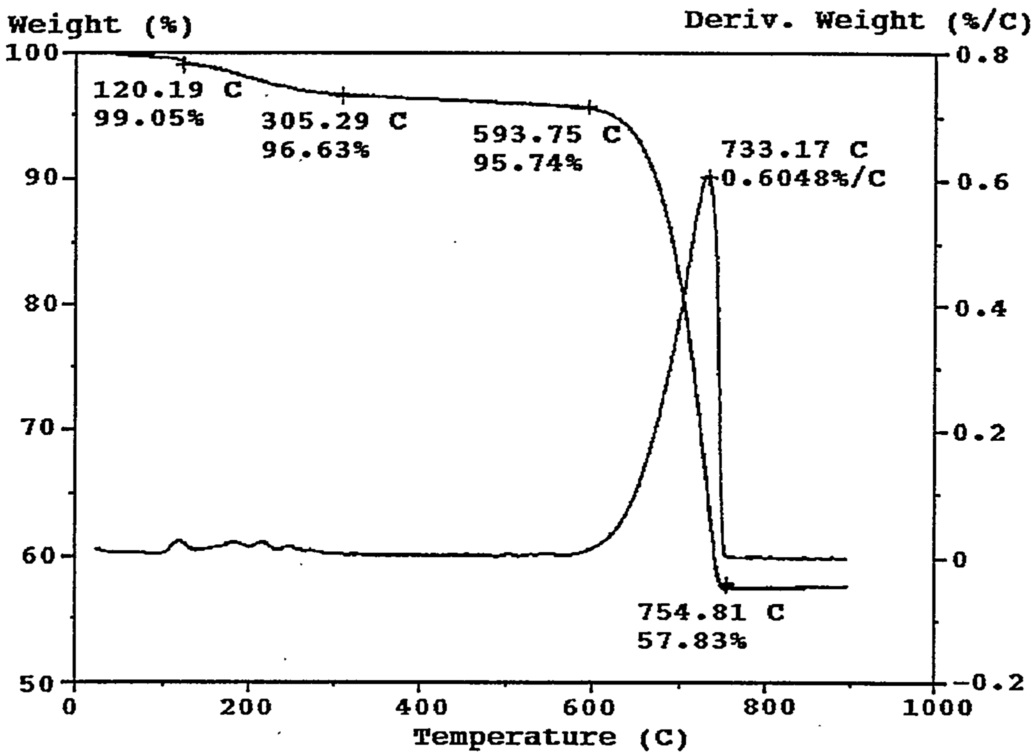

Figure 4: TGA weight loss profile and first derivative for solid by-product ($CaCO_3$) from the ammonium sulfate production.

In summary, the results of these preliminary tests suggest that high quality ammonium sulfate can be produced from the high quality Abbott FGD-gypsum sample at reaction temperature of 70°C and a duration of five to six hours. The quantity and quality of the ammonium sulfate produced may be improved by modifying the current test condition.

For the low quality Newton FGD-gypsum sample that contains mostly calcium sulfite (87.54%), a conversion of calcium sulfite to calcium sulfate will be necessary. Various oxidative conversion processes are being tested, and the results will be discussed in the next quarter.

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DISCLAIMER STATEMENT

This report was prepared by Mei-In M. Chou of the Illinois State Geological Survey with support, impart by grants made possible by the U.S. Department of Energy Cooperative Agreement Number DE-FC22-92PC92521 and the Illinois Department of Energy through the Illinois Coal Development Board and the Illinois Clean Coal Institute. Neither Mei-In M. Chou and the Illinois State Geological Survey nor any of its subcontractors nor the U.S. Department of Energy, Illinois Department of Energy & Natural Resources, Illinois Coal Development Board, Illinois Clean Coal Institute, nor any person acting on behalf of either:

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PROJECT MANAGEMENT REPORT
December 1, 1994 through February 28, 1995

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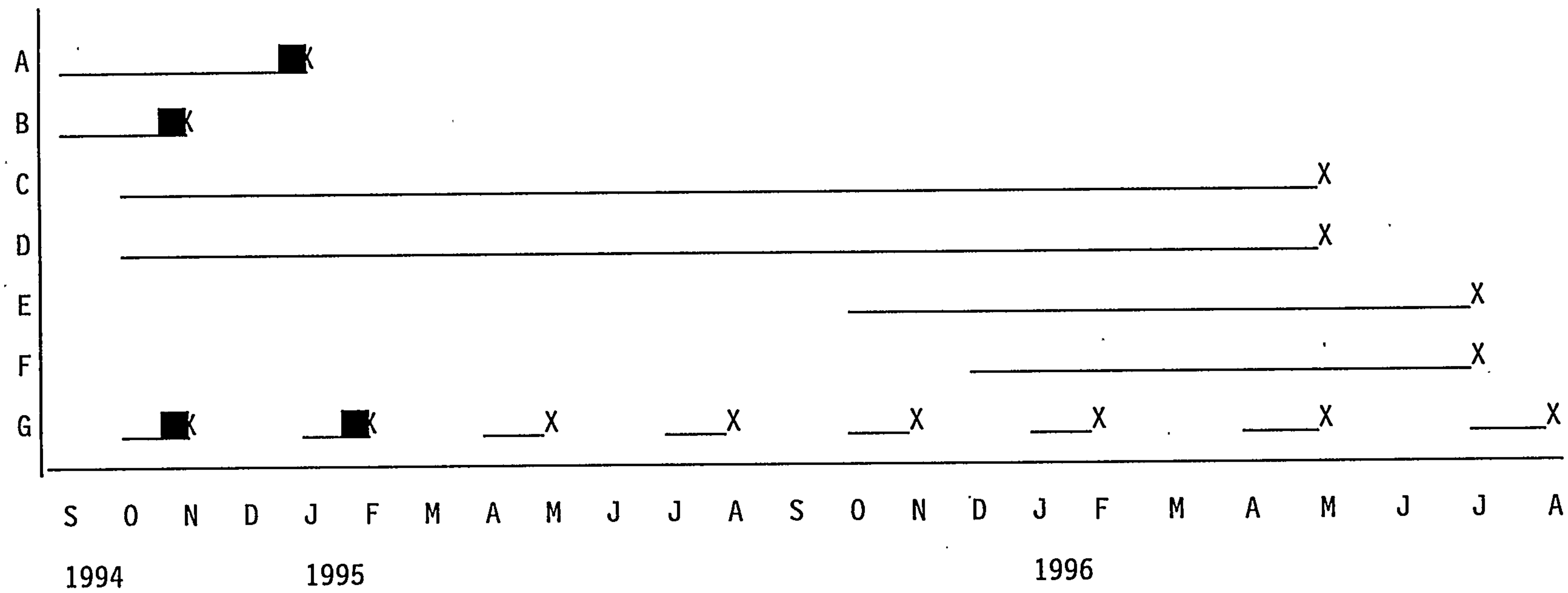
COMMENTS

Analyses services from various laboratories have not yet been paid. These charges are obligated but payments are made on a cost reimbursement basis after the work is completed.

SCHEDULE OF PROJECT MILESTONES



Milestones:

A. Review literature (Task 1)
B. Acquire FGD-gypsum samples (Task 2)
C. Conduct a bench scale study (Task 3)
D. Perform characterizations (Task 4)
E. Conduct controlled green house effect study (Task 5)
F. Develop a process sheet (Task 6)
G. Submit technical and management reports (Task 7)

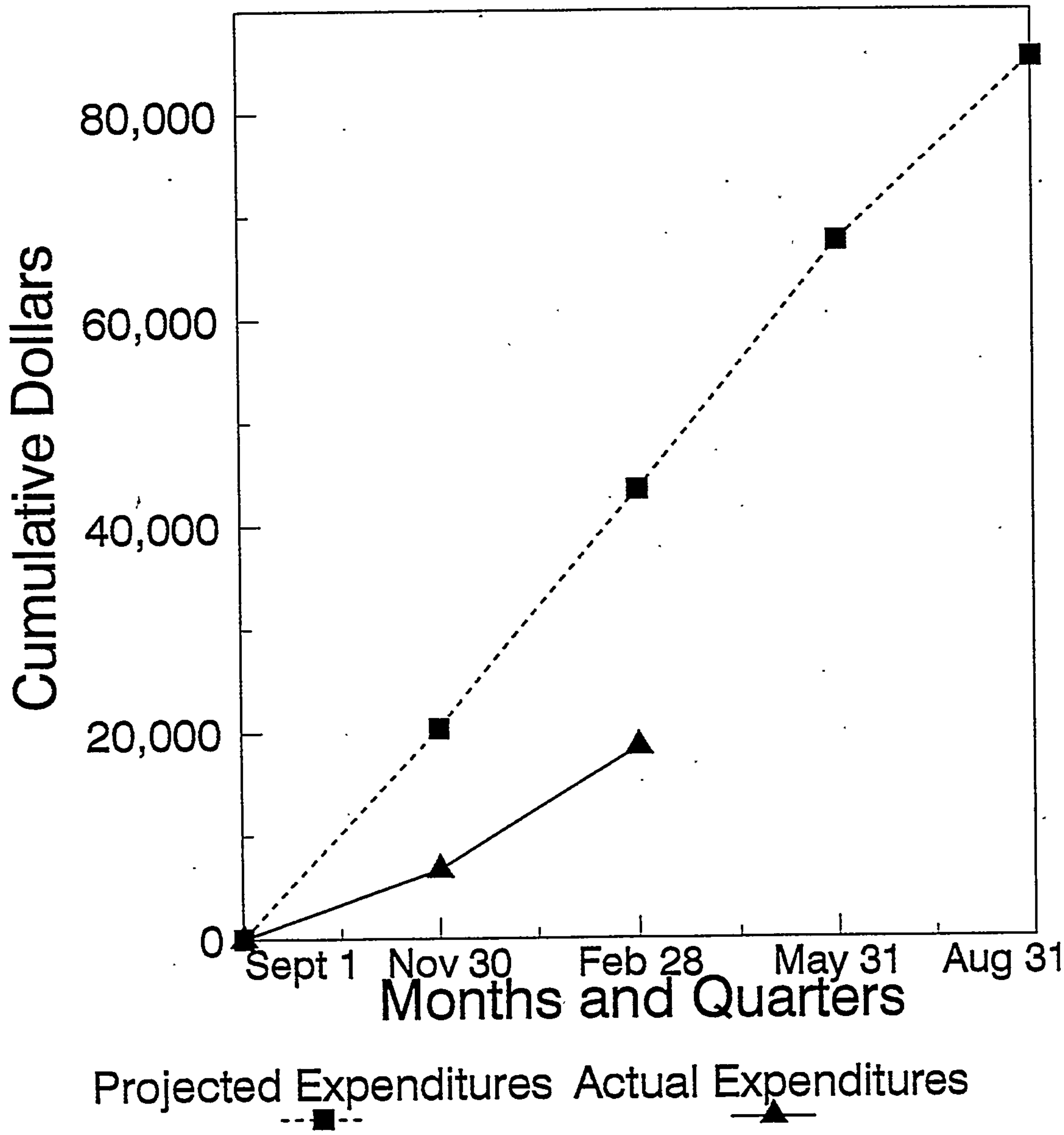
EXPENDITURES - EXHIBIT B

Cumulative Projected and Estimated Expenditures by Quarter

Quarter*	Types of Cost	Direct Labor	Fringe Benefits	Materials and Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Sep. 1, 1994 to Nov. 30, 1995	Projected	8,920	1,984	1,500	0	0	6,137	1,854	20,395
	Estimated	3,960	880	0	0	0	1,229	607	6,676
Sep. 1, 1994 to Feb. 28, 1995	Projected	17,840	3,968	2,800	1,000	2,000	12,274	3,988	43,870
	Estimated	8,684	1,932	225	59	483	5,455	1,684	18,522
Sep. 1, 1994 to May 31, 1995	Projected	26,759	5,952	4,000	2,000	2,000	21,411	6,212	68,334
	Estimated								
Sep. 1, 1994 to Aug. 31, 1995	Projected	33,391	7,614	5,000	2,000	2,000	27,548	7,755	85,308
	Estimated								

COST BY QUARTER - EXHIBIT C

MANUFACTURE OF AMMONIUM SULFATE FERTILIZER FROM FGD-GYPSUM



Total ICCI Award $\underline{\$\ 85,308}$